

LA-UR-02-1617

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in the SOURCES Code System

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Submitted to: American Nuclear Society
2002 Winter Meeting
November 17-21, 2002
Washington, D.C., USA

Los Alamos

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Modification of the Three-Region Problem in the SOURCES Code System

Erik F. Shores

Introduction

The fourth, and most recent, addition to the SOURCES code system is that of a three-region interface (TRI) problem [1,2]. In a manner similar to the homogeneous, interface, and beam-type problems, SOURCES includes methodology to calculate neutron production rates and spectra from the decay [(α,n) reactions, spontaneous fission, and delayed neutron emission] of radionuclides in a TRI configuration. Such an arrangement consists of a middle, or intermediate region, sandwiched between a thick alpha-emitting source region and thick (α,n) target region. The source, intermediate, and target regions may be referred to as A, B, and C regions, respectively (Figure 1). Alpha particles originating in region A may slow to interface "ab", slow through region B to interface "bc", and ultimately slow to a stop in region C. In terms of (α,n) reactions, neutrons may thus be produced in regions B or C (unless, of course, region B is simply a slowing-down material in lieu of a target material). Examples of TRI applications include exotic (α,n) sources, nuclear reactor fuel elements, holdup materials in reprocessing facilities, and storage configurations (e.g. canned actinides).

Range Calculation

An alpha's mean range, R , is simply the expected value in a material of the farthest penetration depth of the alpha in its original direction. The range is obviously an important parameter in the TRI problem and regarding SOURCES, it is noted an intermediate region B's thickness, t , may be any width. In order to determine the alpha source term at interface "bc", SOURCES compares the range of a given alpha to the possible distances encountered (e.g. those arising from an inherent angular dependence). The range is calculated in the "processor" subroutine of SOURCES via three quantities: "dea", the width of the alpha energy bin in units of MeV, "scxb(ig)", the stopping cross section of region B in $\text{eV}/10^{15} \text{ atoms}/\text{cm}^2$, and "anumb", the atom density of region B in units of $\text{atoms}/\text{barn}\cdot\text{cm}$. To produce required units of cm for the range,

three factors are necessary: 10^6 (converting eV to MeV), 10^{24} (converting barns to cm^2), and 10^{15} (an artifact of the stopping cross section units). Considering all three factors, a value of 0.001 should be multiplied by "sum", the variable representing the range, to produce units of cm.

Unfortunately, however, the aforementioned factor of 0.001 was not folded into version 4B of SOURCES. Consequently, it was possible to execute a TRI problem with a region B thickness greater than the range (by an order of magnitude) and still produce neutrons in region C! In other words, region B material that would have otherwise shielded the alphas from region C was effectively transparent to the alphas. Such conditions are obviously incorrect and the source code was recompiled after incorporation of the necessary conversion factor.

Example Problems

Reference 1 contains two fictitious TRI example problems. The first (Figure 1) consists of a thin layer of aluminum adjacent to a slab of plutonium and also contacting a layer of beryllium while the second consists of a CO_2 gap between an americium source and AlB_2 plate. Both examples illustrate proper use of the TRI option within SOURCES, are fully described in the code's manual, and are supplemented with associated output data. The aluminum's intermediate region thickness for the Pu-Al-Be case is 0.1 cm while that of carbon dioxide in the Am- CO_2 - AlB_2 case is 3.0 cm.

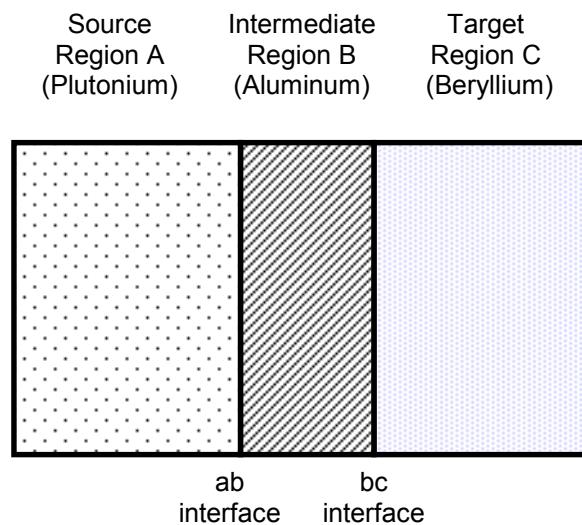


Fig. 1. Schematic of the Three-Region Interface (TRI) Problem

Results

Both examples were executed under SOURCES-4B and the newly corrected version for varied thicknesses of t . Neutron production rates (n/sec-cm^2) as a function of thickness (cm) are provided in Table 1.

TABLE I
Neutron Production Rates for Two Example Problems

Neutron Production (n/sec-cm^2)					
Pu-Al-Be			Am-CO ₂ -AlB ₂		
t (cm)	4B	4C	t (cm)	4B	4C
1.0e-7	2.35e2	2.35e2	1.0e-5	1.59e3	1.59e3
5.0e-7	2.35e2	2.35e2	1.0e-4	1.59e3	1.59e3
1.0e-6	2.35e2	2.35e2	1.0e-3	1.59e3	1.59e3
5.0e-6	2.35e2	2.31e2	1.0e-2	1.59e3	1.58e3
1.0e-5	2.35e2	2.23e2	1.0e-1	1.59e3	1.30e3
5.0e-5	2.35e2	1.70e2	5.0e-1	1.52e3	5.18e2
1.0e-4	2.35e2	1.21e2	1.0	1.43e3	1.36e2
5.0e-4	2.35e2	4.45	1.5	1.34e3	3.62e1
1.0e-3	2.35e2	5.95e-1	2.0	1.26e3	1.92e1
5.0e-3	2.31e2	0	2.5	1.19e3	1.73e1
1.0e-2	2.23e2	0	3.0	1.11e3	1.72e1
5.0e-2	1.70e2	0	3.5	1.04e3	0
1.0e-1	1.21e2	0	4.0	9.80e2	0

In both example problems, the highest energy alpha particle encountered is one of 5.54 MeV from ²⁴¹Am. The calculated range for such an alpha was approximately 0.002 cm in aluminum and 2.9 cm in carbon dioxide (and will vary slightly pending the empirical method used for calculation). For the erroneous case of version 4B, a significant number of neutrons are still produced for values of t greater than the range. As expected for the corrected version of the code, any region B thickness greater than the range stops the alphas and results in zero neutron production in region C. Producing two-region interface problems by eliminating region B indicates production rates of 235 and 1598 n/sec-cm^2 for Pu-Be and Am-AlB₂ problems, respectively.

Conclusions

The SOURCES computer code was upgraded to version 4C as the result of a correction to the three-region interface subroutine. Two example problems were calculated under the new version of the code and produced results consistent with expectation. In particular, the neutron

production approaches that of the two-region interface problem when the intermediate region's thickness approaches zero. As t increases, and is ultimately greater than the range, neutron production in region C decreases to zero.

References

1. WILSON, W.B., et al., "SOURCES 4A: A Code for Calculating (α, n) , Spontaneous Fission, and Delayed Neutron Sources and Spectra," Los Alamos National Laboratory Report LA-13639-MS (September 1999).
2. CHARLTON, W.S., et al., "Derivation and Implementation of the Three-Region Problem in the SOURCES Code System," Journal of Nuclear Science and Technology, Supplement 1, p. 570-574 (March 2000).